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Dynamic Inter-domain Negotiation for Green Algorithms in Optical Networks

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Abstract

This paper presents a dynamic inter-domain negotiation mechanism over green optical networks. The proposed propagation mechanism disseminates the source types of energies to all nodes while it advertises a proposed path attribute called minimum path emission. The paper shows how the dynamic negotiation protocol along with the proposed traffic engineering metric improves the performance of green algorithms. This mechanism helps service providers to control the network Co_2 emission level in WDM networks and keep the network as green as possible.

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Keywords: green networks; energy-aware algorithms; minimum path emission; service level agreement;

1. Introduction

Energy-aware routing mechanisms within green optical networks rely on knowledge of network topology, resource availability, and energy consumption of devices powering the network. This information may be gathered and used by a centralized system, or by a distributed link state routing protocol [1]. In either case, the first step towards network-wide link state determination is the discovery, by each route, of the status of local links to all neighbours. To disseminate traffic engineering (TE) information among entire nodes of a network, the information should be propagated inside and outside the autonomous system (AS), along the path from a source to a destination. For intra-domain TE-information dissemination, OSPF-TE Opaque link state advertisements (LSAs) [2] with newly proposed extensions are used, and for inter-domain TE-metrics propagation, new TE extensions for BGP are proposed in this paper.

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In a multi-homed network topology, link attribute information can be communicated using dynamic negotiation mechanisms [1]. The customer side of the network is exposed to the information from all the service providers to which it is connected. The customer has the choice to pick the service provider that is the most suitable for satisfying the requested connection while meeting the energy-aware algorithm constraints and requirements. This paper presents a dynamic negotiation mechanism considering intra- and inter-domain communications over energy-aware optical networks. The intra-domain negotiation mechanism propagates the link attribute while the inter-domain mechanism advertises the proposed TE path constraints. This paper shows how the dissemination protocol together with the proposed TE attribute improves the performance of energy-aware algorithms. To cope with possible overheads of control messages, an alternative means of communications is employed to reduce overhead and resolve possible scalability issues.

The paper is organized as follows: Section 2 discusses related work. The proposed emission dissemination mechanism and TE extensions are introduced in Section 3. Network performance evaluation is presented in Section 4. Section 5 summarizes the paper discussions.

2. Related Work

In the previous work [1], a dynamic SLA negotiation mechanism for shared mesh optical networks has been introduced. The proposed TE extensions presented in [1] have been applied to OSPF-TE [2] and [3] and BGP-TE [4] protocols considering both intra and inter domain communications. In [1], link attribute as a service level agreement (SLA) parameter is negotiated via intra-domain mechanism, and a proposed SLA-based TE path-attribute has been advertised through inter-domain negotiation mechanism. This paper adopts the idea presented in [1] to dynamically disseminate the level of emission. That is, different types of energy sources [5] for links and paths are considered as the intra-domain information propagation, and a new TE path attribute is considered as the path constraint for inter-domain negotiation in this paper. The new TE path attribute presented in this paper helps energy-aware algorithms to find the paths with the least amount of emission over a network traversing several autonomous systems.

The different types of energy sources and how they are propagated inside a domain has been discussed in [5]. In [5], a green routing algorithm has been proposed to route the traffic through the least energy paths implementing TE extensions to OSPF-TE protocol, named as energy efficient (EE) in this paper. Although [5] has presented a solution for disseminating of energy information inside a network, it has not provided any means of communication between different domains. This paper provides an inter-domain communication between several autonomous systems in multi-homed networks implementing new TE extensions to multi-protocol BGP (BGP-MP) protocol along with a new TE path attribute.

To calculate the amount of Co_2 emission, the amount of energy spent on links and nodes are calculated. The work in [6] has introduced values for different types of energy sources to calculate the amount of consumed energy in terms of the amount of emission.

3. Emission Dissemination Mechanism

3.1. Link Emission Factor Dissemination

Definition 1: The emission factor of a link is calculated based on the number of optical amplifiers on the link and the degree of the nodes at two sides of the link. The emission factor of the link L between nodes i *and* j, EF_L, can be calculated through (1), where EF_L is the emission factor of the link L, E_{amp} is the average energy consumption of amplifiers powering link L, N_{amp} is the number of amplifiers on the link L, E_{node} is the average energy consumption of nodes owning the link L, n is the degree of nodes, and s is the type of energy sources powering links and nodes.

$$EF_L = \{E_{amp} * N_{amp} + \frac{E_{node}}{n}\} * s \tag{1}$$

The new OSPF-TE extensions proposed in [5] is adopted here to disseminate link parameters inside a domain. As discussed in [5], Type-10 Opaque LSAs are suitable choice since type-10 opaque LSAs are not flooded beyond the borders of their associated area. In addition, as defined in [7], Type-11 opaque LSAs can be suitable choice to disseminate the link parameters inside an AS. In OSPF-TE, a top-level link type-length-value (TLV) triple in payload field describes the characteristics of a single link [8]. The link TLV and its sub-TLVs have a format of Table 1 as described in [5]. The new sub-TLV carrying and propagating the link emission factor (EF_L) inside an AS is defined in Table 2. As it has been discussed in [5], the values of sub-TLVs for TE-LSAs vary based on the type of energy sources which power devices in the network. For instance, solar energy may take the lowest value as the greenest source of energy and coal the highest [5].

Table 1. Link TLV payload format

Link Type	Link Length
Link *1* Sub-TLV	
…..	
Link *n* Sub-TLV	

Table 2. New EF_L sub-TLV

EF_L Type	EF_L Length
EF_L Value	

3.2. Path Emission Dissemination

Definition 2: The emission factor of the path *P*, EF_P, is the sum of emission factors of links (EF_{Li}) forming the path *P*.

$$EF_P = \sum_{L_i \in P} EF_{L_i} \tag{2}$$

It is a wise idea to employing some alternative means of communication, to reduce the overhead and resolve the possible scalability issues of disseminating link attributes in control plane of GMPLS networks. One way of reducing link state overheads is to use the concept of path state advertisement (PSA) [9] rather than LSA. An improved OSPF-TE protocol introducing PSA concept has been introduced in [9]. The proposed protocol in [9] not only disseminates link state information very effectively, but also advertises link information, if necessary. The parameters shown in Table 3 and Table 4 are proposed in this paper to be carried using the path TLV payload and PSA sub-TLV proposed in [9].

Table 3. Path TLV payload format

Path Type	Path Length
EF_P value change Sub-TLV	
EF_P Sub-TLV (optional)	

Table 4. PSA Sub-TLV for EF_P

EF_P value change Type	EF_P value change Length
EF_P value change	
EF_P Type	EF_P Length
EF_{Pl}	
….	
EF_{Pm}	

As a special case discussed in [9], the “EF_P value change Sub-TLV” field, in the path TLV payload presented in Table 3, is the increment or decrement of emission factor in the lightpaths, and the “EF_P Sub-TLV” field represents the Co_2 emission produced in all links forming a path. The theoretical analyses and simulation results in [9] have shown that OSPF-TE’s control overheads could be reduced between 3 and 7 times compared to the conventional flooding mechanism. Based on the graphs presented in [9], the blocking probability has also been reduced, and the performance of optical networks has been improved significantly.

3.3. Energy-aware Inter-domain Dissemination

Definition 3: $MPE_{(i,j)}$ is the minimum path emission factor between any source and destination pair of i and j. The way $MPE_{(i,j)}$ is calculated is presented in Algorithm 1. $MPE_{(i,j)}$ is a number which represents the minimum amount of Co_2 emission of any path from any source to any destination.

In a multi-homed network in which the customer can be served by several service providers, the MPE algorithm dynamically calculates the lowest path emission offered by an autonomous system for any given source and destination pairs of nodes at any time that a request is received. Having $MPE_{(i,j)}$ propagated all over different domains, edge routers will have a picture of green routes from any source to themselves and vice versa. It consequently helps decision making nodes to manage customers` requests, specifically high-priority requests, based on the least level of emission of paths in the network. For instance, this will help to increase the chance of accommodating more high-priority connection requests compared to existing shared-mesh protection algorithms over WDM optical networks.

Algorithm 1: MPE matrix calculation

Input: Connection request for a pair of source and destination (*i,j*)
Output: $MPE_{(i,j)}$, MPE matrix
1. Modify the cost of the links in the network using EF_L formula presented in (1)
2. Find the least cost path *P* applying *Dijkstra* algorithm [10] based on the modified link costs
3. Calculate the emission factor of the path *P* employing EF_P formula presented in (2)
4. Save EF_P as *MPE(i,j)*
5. Repeat steps 1 to 4 for all source and destination pairs to build MPE matrix

Since in a general case there is no interior gateway protocol (IGP) peering between two different ASs, to find a way to get LSAs describing its TE properties into the TE database, [11] suggests that edge routers can advertise the external link states, internally to its AS and generate an LSA describing its own side of a link. Since in BGP, no topological and/or state information is allowed to be disseminated beyond domain boundaries [12], the link emission information cannot be disseminated from inside one AS to another. The proposed TE-based path attribute defined in this paper, MPE, not only distributes the minimum path emission which is calculated in any internal routers and sent from the edge routers of an AS to the other ASs, but it also reduces the routing protocol packets' overhead caused by propagating link emission. Based on [11], the link state of the links connecting different ASs is advertised inside the ASs by edge routers of the same ASs.

In the conventional BGP [13], the advertisements propagated between BGP routers are encapsulated in the update messages. To consider TE-constraint, a new path attribute is added into BGP as an extension. The proposed TE-metric is advertised along with the path information in both intra-AS and inter-AS manners using internal BGP (IBGP) and external BGP (EBGP). The proposed format of the extension is in form of TLV format, where the proposed TE-attribute carries a group of TLV fields, specifying the value of the corresponding TE metric.

The MPE path-attribute sub-TLV in BGP-TE update packets for carrying MPE TE-constraint in an edge router (ER) calculated from any node inside the corresponding AS (including the other ERs) is presented in Table 5.

Table 5 New MPE sub-TLV

MPE Type	*MPE* Length
$MPE_{(1,j)}$	
……	
$MPE_{(m,j)}$	
MPE_{total}	

The packet routed from one AS to another AS should be routed through one of the edge routers. Routers inside an AS advertise link emission factors of associated links into the AS. Using this information, the MPE matrix is built in all routers inside an AS including edge routers. Then all the edge routers of an AS have the same matrix of form (3).

$$MPE_{mxm} = \begin{bmatrix} MPE_{(1,1)} & \cdots & MPE_{(1,j)} & \cdots & MPE_{(1,m)} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ MPE_{(m,1)} & \cdots & MPE_{(m,j)} & \cdots & MPE_{(m,m)} \end{bmatrix} \tag{3}$$

Unlike regular routers inside the AS that only advertise link emissions, the j^{th} edge router, ER_j, will advertise all the information of the j^{th} column of MPE matrix of the associated AS through the proposed sub-TLVs of Opaque LSAs presented in Table 5, in addition to the link emission factor of external links. The total minimum path emission of a path traveling from node s inside the n^{th} AS, AS_n, to d inside the p^{th} AS, AS_p, will be calculated through (4), in which MPE is the minimum path emission matrix in an AS, MPE_{AS_k} is the minimum value of path emission of k^{th} AS from an ingress edge router ER_i to an egress edge router ER_j as calculated in (5).

$$MPE_{total} = MPE_{AS_n}(s,t) + \sum_{k=n+1}^{p-1} MPE_{AS_k} + MPE_{AS_p}(q,d) \tag{4}$$

$$\forall (i,j) \in AS_k's\ nodes: \quad MPE_{AS_k} = Min\{MPE_{(ER_i,ER_j)}\} \tag{5}$$

Here, each edge router keeps two matrices. One from its associated AS which is to be advertised to the other AS, and the other which is received from another AS informing regarding the conditions on the neighbouring AS. In the case of NSFNet network topology shown in Figure 1, the j^{th} edge router will advertise an MPE sub-TLV of 14 MPE values including the j^{th} column of the MPE matrix plus MPE_{total}.

4. Performance Evaluation

4.1. Re-provisioning Green algorithm

To show how the inter-domain negotiation mechanism proposed in this paper lowers the amount of Co_2 emission and picks the greener paths, the re-provisioning green algorithm (REGA) is presented and discussed in Algorithm 2. Algorithm 2 dynamically calculates minimum path emission of all pair of source and destination in the network presented in Figure 1. Then it re-provisions the previously established connections comparing the emission factor of the established connection to the minimum possible path emission. If the emission factor of the established path is less than MPE of the same source to destination pair over a specific threshold, ξ, it replaces the path with the new route by running the path calculation process again based on the updated network status. Algorithm 2 discusses the steps taken in this mechanism.

Algorithm 2 REGA algorithm

Input: established connections between any pair of source and destination (i,j), $n \leftarrow 1$
Output: re-provisioned path P

1. Process the n^{th} established connection between (i,j)
2. Modify links cost based on the emission of links using (1)
3. Run Algorithm 1 to calculate the elements of MPE matrix using (5) and (6)
4. IF $EF_P(i,j) \leq (1/\xi)\ MPE(i,j)$
    5. Re-calculate the k shortest paths between source and destination using *Yen's* k-shortest path algorithm [14]

6. Calculate the Co_2 emission factor of all *k* possible paths using (2)
7. Find the lowest cost path, *P* (greenest path), applying *Dijkstra* algorithm [10]
8. IF *P* found
    9. Assign resources of the new path
    10. Release resources of the established connection
    11. Update network graph, network resources, emission factor table, and MPE matrix
12. ELSE $n \leftarrow n+1$ and go to 1

13. ELSE $n \leftarrow n+1$ and go to 1
14. $n \leftarrow n+1$ and go to 1

4.2. Simulation environment

The simulation network topology is the NSFNet network presented in Figure 1. Each link has 16 available wavelengths. It is assumed that every pair of nodes represents edge routers of an autonomous system. The numbers on the links in Figure 1 represent node distances in km. The first fit (FF) method for wavelength assignment is used without the continuity constraint. Each inline amplifier is placed at every 80 km of optical links. Any random type of energy sources can power nodes and links in the network and this information is disseminated through the network using the method proposed in this paper. The arrival process of connection requests follows Poisson process with mean arrival rate of 6 minutes. The holding time of the connections follows an exponential distribution with the mean value of 12 hours. It is assumed that power change interval is every 6 hours. The performance of the algorithm is investigated for various values of ξ=0.3, ξ=0.7, and ξ=1.0.

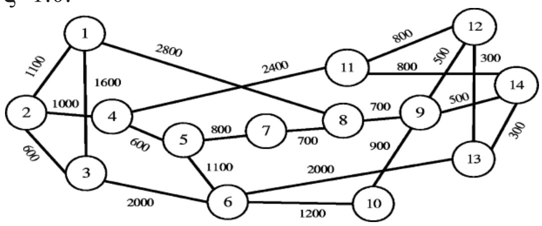

Figure 1. NSFNet topology

4.3. Performance analysis

To investigate how the inter-domain propagation mechanism presented in this paper affect a re-provisioning infrastructure, the REGA algorithm will be compared to the energy efficient (EE) algorithm [6] and [15] for various values of ξ. Figure 2 and Figure 3 compare EE algorithm which does not benefit from inter-domain negotiation infrastructure with REGA algorithm which takes advantage of an inter-domain path attribute, MPE.

As figure 2 shows, the amount of Co_2 emission in the mechanism benefiting from inter-domain negotiation, REGA, is 13% less than the one with no inter-domain negotiation. Figure 2 also shows how the path attribute proposed in this paper can help the algorithm to choose the path with the least amount of emission. This fact has been shown by changing ξ factor. As the re-provisioning factor increases (larger values ofξ), the amount Co_2 emission decreases.

Figure 3 shows that the re-provisioning factor does not affect the resource usage of the network. As Figure 3 shows, the average number of wavelengths assigned to the paths chosen by REGA algorithm is less than the EE algorithm while it does not cause significant changes on resource usage when the re-provisioning factor changes.

As shown in Figure 4, the blocking rate of the proposed mechanism for different re-provisioning factor is not changing much. This shows that the re-provisioning mechanism proposed in this paper does not affect the number of served connection requests which can be counted as a fairly good trade-off.

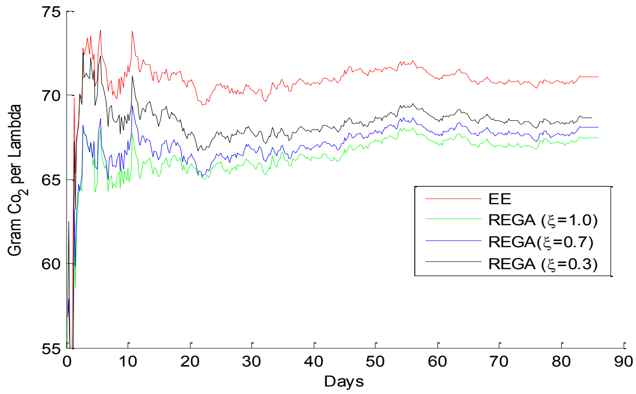

Figure 2 The average Co_2 emission per connection per wavelength

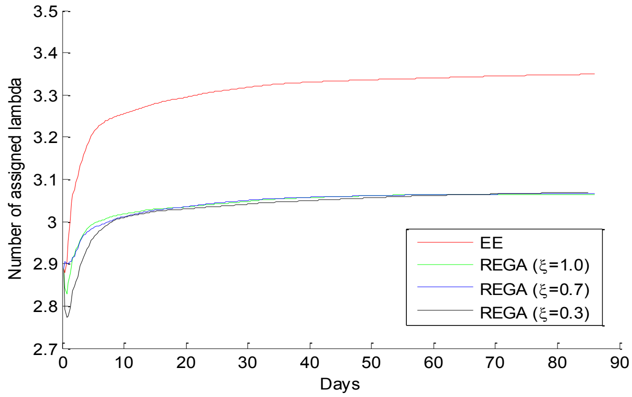

Figure 3 The average wavelength usage per connection

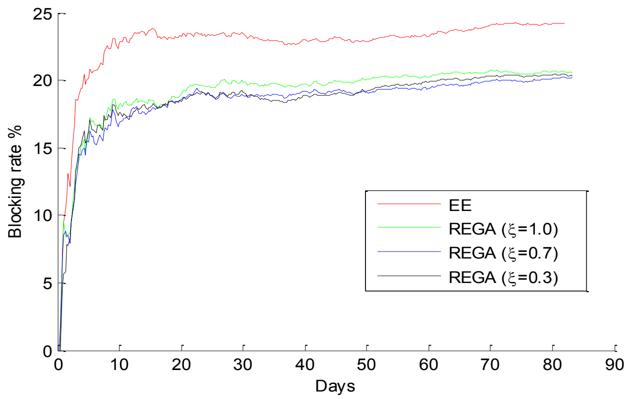

Figure 4 Blocking rate

5. Conclusion

This paper has presented a dynamic intra- and intern-domain path attribute dissemination mechanism for green optical networks. The proposed TE extensions applied to OSPF and BGP protocols consider both intra and inter domain communications. The paper has shown how a parameter dissemination mechanism together with the proposed TE metric can improve the performance of different energy-aware algorithms. Since the proposed mechanism in this paper may cause heavy control overheads when disseminating link/path attributes, an alternative means of communication has been employed to reduce the overheads and resolve the possible scalability issues. The performance analysis has also shown that the proposed mechanism can be easily scalable using the path state advertisement concept, and also has verified that the scheme introduced in this paper has had a better network performance.

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